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USING SIMULATION TO EXAMINE LIVE-FIRE TEST CONFIGURATIONS

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ABSTRACT

Man-Portable Air-Defense System (MANPADS) missiles are threats to military aircraft. Analytical models are used to help design military aircraft to survive a variety of attacks, including those from Man-Portable Air-Defense Systems. These models need accurate fragment capture data consisting of the fragment size and velocity resulting from weapon detonation. Accurate data require accurate testing which in turn requires effective test design infrastructure. We model this test infrastructure. MANPADS missiles are detonated within test arenas that have make-screens placed on the arena walls to capture fragment impact data. Our model mimics the test process and provides a quantitative metric with which to examine and compare test arena configurations. We overview our model and quality metric and offer a case study in which these are used to find a robust arena make-screen configuration.

1 INTRODUCTION

Military aircraft systems are designed to survive being attacked. The weapons deployed against military aircraft can be particularly lethal. Since military operations often require military aircraft to operate in areas of high threat, these systems must be designed to avoid, counter and, if hit, survive in these high threat areas. Aircraft survivability is the general label applied to research, development and design efforts focused on ensuring our military aircraft systems meet these threats.

A particularly troublesome threat are Man-Portable Air-Defense System (MANPADS) missiles. These missiles are small, portable and lethal, shoulder fired and best suited for ground targets and low-flying aircraft (Bureau of Political-Military Affairs 2011). Their size makes them easy to transport and hide and thus they are quite popular in the more unsavory activities. There are an estimated 500,000-750,000 MANPADS missiles currently stockpiled (Schroeder 2007).

MANPADS analytical models require good data on fragment dispersal and fragment velocity at impact. Such data are obtained via live-fire testing which involves detonating a test missile in a specially constructed test arena. Figure 1 depicts one such arena with the missile statically loaded. The walls of the test arena provide a means to record fragment impact times (for fragment velocity estimates) and to recover the fragments (weighed to calculate residual mass). Fragment impact times are recorded when the fragments impact specifically designed panels mounted on the arena walls. The panels, or make-screens, are of varied sizes and are arranged on an arena wall based on expert opinion. The panel arrangement and the effectiveness of that arrangement are the focus of our research.

2 A FRAGMENT TEST SIMULATION MODEL

Garee et al. (2014) describe the design of our fragment capture simulation for MANPADS testing. We provide a general overview here. The model, developed in MATLAB, simulates the dispersal of missile

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14. ABSTRACT

Man-Portable Air-Defense System (MANPADS) missiles are threats to military aircraft. Analytical models are used to help design military aircraft to survive a variety of attacks, including those from Man-Portable Air-Defense Systems. These models need accurate fragment capture data consisting of the fragment size and velocity resulting from weapon detonation. Accurate data require accurate testing which in turn requires effective test design infrastructure. We model this test infrastructure. MANPADS missiles are detonated within test arenas that have make-screens placed on the arena walls to capture fragment impact data. Our model mimics the test process and provides a quantitative metric with which to examine and compare test arena configurations. We overview our model and quality metric and offer a case study in which these are used to find a robust arena make-screen configuration.

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Figure 1: A MANPAD missile centered in a fragment capture arena (Czarnecki et al. 2011). Rectangular patterns on the walls show the edges of the make-screens mounted on the test arena walls.

fragments. This dispersal pattern is based on some user-defined distribution, data from other models, or even from live-fire test events. Fragment trajectories are calculated and evaluated for impact against the arena test walls.

In actual tests, the arena walls are covered with make-screens. These make-screens vary in size, are tethered to data channels, and are used to collect the test data (see Figure 1). As fragments impact the screens, the time of impact is recorded over the data channel. This impact time is used to estimate the fragment velocity. After the test is complete, the fragments are physically removed from the arena walls, measured and counted for each make-screen.

The recording fidelity of each make-screen prohibits assigning impact times to each specific fragment; only the time of an impact is recorded. Thus, the velocity estimate assigned for each frament is the average velocity for all impacts against that make-screen.

The simulation mimics this test process. Data input defines the make-screen configuration implemented. Fragment impacts are then assigned to the make-screen impacted. Each fragment impact time is used to calculate the average velocity for all impacting fragments on that make-screen. The difference with the simulation is that the actual fragment velocities modeled are known (assigned at fragment creation) which provides a means to develop assessment metrics for a given make-screen configuration. Such a metric can be used to design more effective test arenas and in-turn provide higher quality test data. Figure 2 shows a simulation result with fragments scattered against the arena walls having a simple make-screen configuration assigned to it.

3 A QUALITY METRIC FOR ARENA CONFIGURATIONS

Garee (2014) defined the characteristics needed in a metric for arena configuration comparisons and developed such a metric. This metric is based on mean absolute velocity error (MAVE) for a fragment, which is then aggregated into a measure for the make-screen and finally aggegated into a measure for the arena configuration. For n^s make-screens, define a fragment true velocity as v_f and its estimated velocity as v_s, then calculate MAVE for screen s as

$$MAVE^s = \frac{1}{n^s} \sum_{f=1}^{n^s} \left| v_f - v_s \right| \qquad s = 1, \dots, n^s. \tag{1}$$

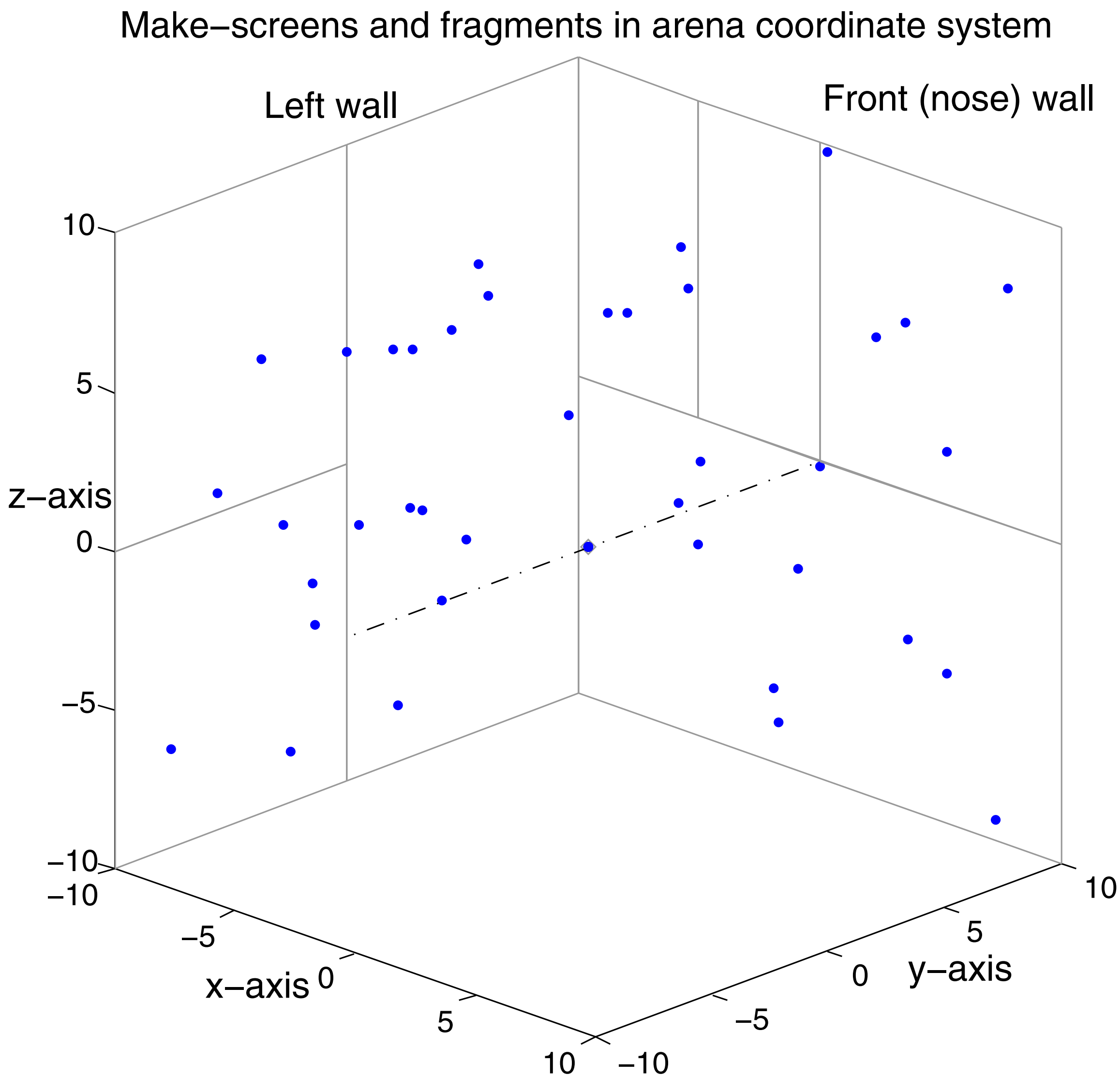

Figure 2: Sample arena with fragments. Twenty fragments are displayed on each wall.

This value, $MAVE^s$ is normalized to $Q^s = 1 - MAVE^s/MAVE^*$ where $MAVE^*$ is the worst-case value. The score for the arena configuration is then defined as

$$Q^a = \frac{1}{M} \sum_{s \in S_{active}} Q^s, \tag{2}$$

where S_{active} is the set of screens receiving a fragment impact and $M = |S_{active}|$. Larger Q scores reflect more effective arena configurations. See Garee et al. (2014) for more details on the metric development.

4 FINDING ROBUST CONFIGURATIONS

It should be obvious that any fragment pattern will be best served by a particular make-screen arrangement tailored to that fragment pattern. The analytical challenge is to find the make-screen arrangement that does the best job against any of the many potential fragment patterns to which it may find itself subjected.

The current simulation model is quite useful for assessing make-screen arena configurations against various fragment pattern as both the make-screen configuration and fragment pattern are user-defined. The following example from Garee (2014) demonstrates how to find robust configurations.

Hill and McIntyre (2000) worked with a large-scale linear program (LP) and defined a "robust solution" as the particular military force structure suggested by the LP as providing some best overall solution evaluated against some set of defense planning scenarios. In the current context, we seek some make-screen arena configuration that provides some best overall performance against a range of fragment patterns. The current simulation requires the make-screen configuration as input to the simulation so the search for a robust make-screen configuration requires using a suite of configurations. For the example we limit the arena size to a single wall to ease the presentation and do not limit the number of make-screens that can be placed on that wall.

Figure 3 provides the six varied configurations used in the example. These configurations were manually generated and intended to provide some range in the configuration options. These six configurations also vary the complexity of the configuration realizing that more make-screens require more data channels. Figure 4 shows the four sample fragment distribution patterns used for the robust analysis. These patterns are not typical of live-fire test results nor do they come from existing fragment pattern models. The patterns were generated to provide a varied sample of patterns. No random fragment patterns are used.

Each of the patterns were tested against each of the make-screen configurations and the quality scores compiled. Those results are provided in Table 1. We note that configuration D does the poorest across the board. This configuration uses the least number of make-screens, so in terms of resources would probably be the cheapest, but the large make-screen size means more fragments impact each make-screen thus causing the average velocity calculation to involve more fragments and be applied to that larger number of fragments. The best performing configurations, in terms of mean quality score, are configurations A and F. However, we note that the performance of configuration A has more variability than we see in the performance of configuration F. Based on the overall consistent performance and the highest overall mean quality score, this example finds configuration F to be the most robust of the make-screen arena configurations considered.

5 CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

This paper summarizes a simulation model of MANPADS missile detonation and presents the effectiveness measure developed to assess arena make-screen configuration performance versus some missile fragment dispersion. We present as a case study an example where the model can be employed to find a robust make-screen configuration.

Our work is still preliminary and evolving. The current research represents just the initial effort. Subsequent work will enhance the model to consider full arena enclosures and will consider other types of make-screens.

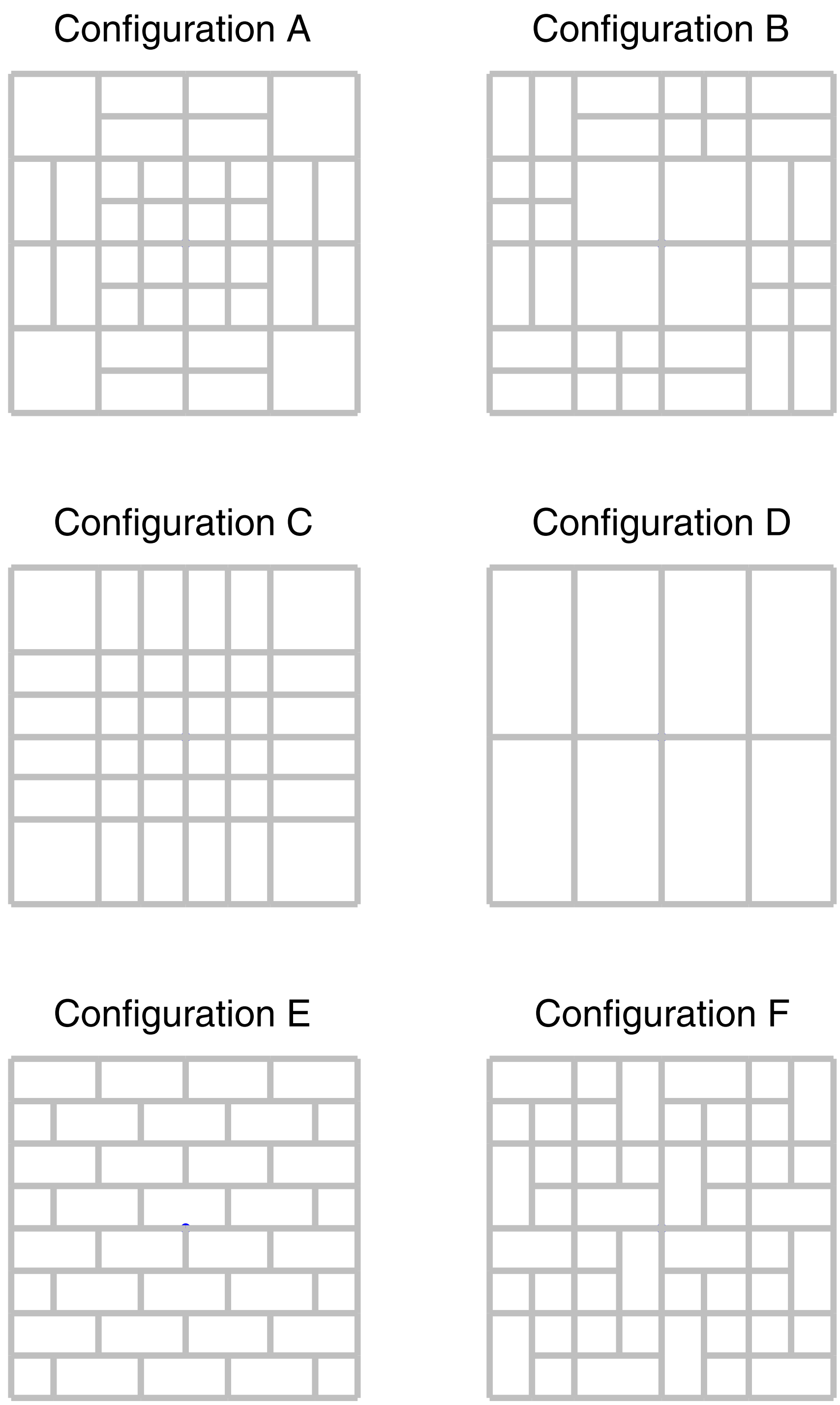

Figure 3: Six make-screen configurations for an 8 x 8 unit wall. Each configuration is arbitrarily created from a limited pallet of make-screen sizes. The smallest make-screen is a one-unit square.

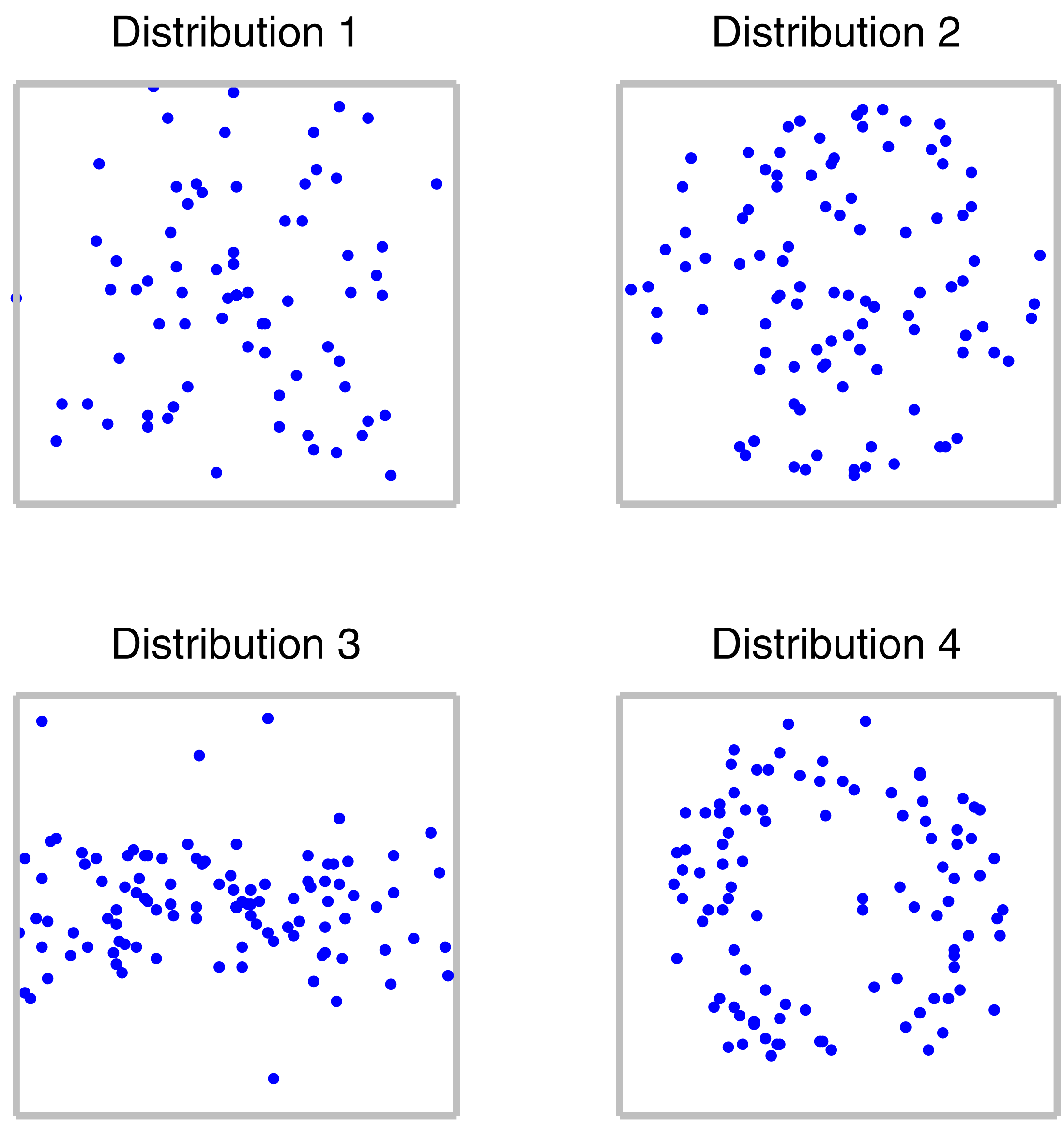

Figure 4: Fragment distribution patterns used for robust make-screen configuration analysis.

Table 1: Arena data quality scores for various pairings of arena configurations and fragment distributions. The highest score for each distribution is in boldface.

		Fragment Distribution				
	Q^a	1	2	3	4	Mean
Arena configuration	A	0.7511	0.6788	0.6979	**0.7652**	0.7232
	B	0.7628	0.6745	0.6946	0.6879	0.7050
	C	0.7608	0.6923	0.7099	0.7110	0.7185
	D	0.5828	0.6006	0.4798	0.5511	0.5536
	E	0.7095	0.6757	0.6833	0.6930	0.6904
	F	**0.7825**	**0.7101**	**0.7249**	0.7292	**0.7367**
	Mean	0.7249	0.6720	0.6650	0.6896	

Our research challenge is how to generate reasonable make-screen configurations. The configurations used in our example are manually developed. Computer generation requires considering make-screen sizes, shapes, placement on the wall and the number of each placed on the arena walls. This is not an easy problem. However, such a generation approach can be exploited in a simulation-based optimization search process to allow the model to find robust make-screen arena configurations.

Disclaimer

The views expressed in this article are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense or the U.S. Government.

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